Plasma irregularities in the F-region studied by ground-based optical and radio techniques in the Southern Space Observatory, São Martinho da Serra, Brazil.

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Plasma irregularities in the F-region are studied by ground-based optical and radio techniques at the Southern Space Observatory, São Martinho da Serra (29.4°S, 53.8°W; dip latitude 19.6°S), Brazil. This site has relatively higher geographic latitude for a location under the southern crest of the equatorial ionization anomaly, and thus observations can be used to study the penetration of both equatorial and midlatitude structures into the low latitudes region. The new 4” all-sky imaging system installed at this site in Brazil consists of a Mamiya RB67 37mm/F4.5 medium-format achromatic fisheye lens which images telecentrically onto a six-position filter-wheel that containing narrow band interference filters for several nightglow emissions (OI 630.0 nm, OI 557.7 nm, OI 777.4 nm, background at 578.0 nm, N_2^+ 427.8 nm and Nad 589.3 nm). The imager is equipped with a PI/Acton Pixis 2048B CCD camera with 27.6 mm x 27.6 mm active area and quantum efficiency higher than 90% in the visible region. The main purpose of this work is to investigate and present the occurrence of dark ionospheric plasma band structures in the all-sky images associated with medium scale traveling ionospheric disturbances (MSTIDs) probably associated with Perkins Instability originating in the mid-latitude region. Also, the coupling between both the mesosphere and F-region is investigated during the propagation of these irregularities using all-sky images and ionosonde data. In this work, salient features from these observations will be presented and discussed.

1. Introduction

Both midlatitude and equatorial spread-F has been studied for many years, but its understanding remains incomplete despite considerable progress. We present here a case in which both features, airglow depletion associated with RTI and dark band structures (DBS/MSTID) associated with mid-latitude instability are seen simultaneously in the OI630 nm emission all-sky images in the southern hemisphere. This is a special situation in which two different electrodynamical phenomena have been detected simultaneously, indicating the presence of a transition region.

The tropical spread-F (ESF) phenomena, which show diffuse echoes on the ionograms during nighttime, have been the subject of intensive observational (ground-based optical, radio and radar techniques and in-situ satellite and rocket experiments) and theoretical investigations for many years. The continuing interest in the studies related to the equatorial spread-F irregularities increased from its implications for trans-ionospheric communications and navigation systems. These irregularities are often characterized by transequatorial plasma-depleted magnetic flux tubes, referred to as plasma bubbles, and result from the Rayleigh-Taylor Instability process at the bottomside of the F-region (Haerendel, 1973) and rise to heights of much over 1500km at the magnetic equator (Sahai et al., 1994).

Regarding to the dynamic, the ionospheric plasma bubble zonal drift velocities have been studied using wide-angle airglow imaging techniques (Mendillo and Baumgardner, 1982; Fagundes et al., 1997; Pimenta et al., 2001a,b), as well as using scan OI 630 nm airglow photometers (e.g. Sobral et al., 2009). They have also been studied from ionosonde, vector electric field and ion drift measurements on board the Dynamics Explorer-2 satellite (e.g. Anderson et al., 1987). However, the generation mechanisms of this kind structure remains incomplete despite considerable progress. Seeding of spread-F by gravity-wave-induced perturbations is a widely conjecture idea and also offers a possible handles on day-to-day and even seasonal and longitudinal variability of spread-F occurrence. However, there is a lack of direct evidence in radar and optical data illustrating the details of F-region seeding events. On the other hand, Kudeki and Bhattacharyya (1999) presented a new perspective on equatorial spread-F generation. They showed observational results about the post-sunset vortex above Jicamarca and the relative placements of a bottom-type spread-F layer and a bubble emerging from the vortex.

Nighttime medium-scale traveling ionospheric disturbances (MSTIDs) that are related with spread-F (well know in literature as midlatitude spread-F) are frequently observed at middle and low latitudes (Garcia et al., 2000; Martinis et. al., 2006; Pimenta et al., 2008b). However, this kind of structures are not at well understood. Recent statistical studies of two-dimensional MSTID images over Brazilian and Japanese sectors using OI630 nm airglow imagers indicate that the occurrence of MSTIDs is very high in winter in Southern Hemisphere (summer in Northern Hemisphere). The ionospheric Perkins instability is a likely mechanism in generation these MSTIDs, since it can explain the northeast-southwest phase surface in Southern Hemisphere or northwest-southeast phase in Northern Hemisphere. However, as point out by Kelley and Fukao, 1991, the growth rate of the instability is too small to develop in the nighttime ionosphere at middle latitudes. In additional, the instability cannot explain the observed systematic northwestward motion of MSTIDs in Southern Hemisphere (southwestward motion in the Northern Hemisphere). Kelley and Makela, [2001] introduced a northwest-directed polarization electric field parallel to the MSTID phase surface to explain the southwestward motion. In this paper, we report at the first time simultaneous dark band structures in the OI630.0 nm emission all-sky images associated with both Rayleigh-Taylor and Perkins instabilities and their effects in the thermosphere/ionosphere dynamics.

2. Observation and discussion

Using ground-based measurements we investigate a curious event on February 26-27, 2006, in which both features, airglow depletion associated with RTI and dark band structures (DBS/MSTID) associated with mid-latitude instability are seen simultaneously in the OI630 nm emission all-sky images from 02:36UT to 03:47UT as show in the Figure 2. The local time (LT) at Cachoeira Paulista is 3 hours behind of the universal time (UT). The white arrows in this figure indicate the plasma bubble evolution to eastward whereas blue arrows indicate DBS/MSTID propagating slowly to northwestward. Also, is possibly to see an ionization tongue during the event, represented by the highlight region in the images.

2.1. On the midlatitude spread-F (DBS/MSTID). Regarding to the Dark Band Structures (DBS/MSTID) observed in the OI630nm images (indicated by the blue arrows), the most notable feature is their tendency to be aligned from northeast to southwest and drift towards the northwest with average speed of about 25 m/s. The structure is dark, indicating low emission corresponding to zones of the F-region above or bellow of 220–300 km. The azimuth angle created by this feature is in the direction parallel to their long axis (northeast to southwest) and is ~20° west of the magnetic meridian. Due to the low velocity, this structure is a little different as reported by Pimenta et al., 2008b.

A Digisonde 256 (DGS256) located at the same site was used to obtain vertical sounding data of the ionosphere during this night. The digisonde observations around 02:45UT and 04:00UT registered abrupt increases in both the F-layer peak (hmF2) from 320km to 360km height and base height (h'F) from 240km to 280km when DBS/MSTID passed over Cachoeira Paulista (Figure 3). Likewise, the extreme modulation of the F layer in Cachoeira Paulista is evidence that the F-layer peak height undergoes severe altitude excursions during the passage of DBS. Unfortunately we do not have all-sky images before 02:36UT and after 03:47UT.

The uplift in the F region can be caused by upward **E**x**B** plasma drifts driven by a zonal eastward electric field inside de DBS/MSTID or a meridional equatoward wind. The large electric fields inside of spread-F measured by Behnke (1979), imply that the F-region uplifts are caused by eastward electric field rather than equatoward neutral wind. In addition, Kelley et al. (2000) have recently shown that the internal electric field inside the depleted airglow regions is larger than the background field and has a large northward component.

Like others researchers, we conjecture that the Perkins instability might be involved in the formation of DBS/MSTID in the mid-latitudes region. It should be noted that the ionospheric Perkins instability, which is a possible cause of DBS/MSTID, is an electrostatic instability based on the coupling between ionospheric current and conductivity leading to electric field and conductivity oscillations. This instability can be seeded by neutral wind oscillations, such as gravity waves, but just as an initial perturbation for the electrostatic instability. However, the traditional linear Perkins theory is now argued to have two deficiencies that we will address here. First is the well known issue of small growth rate, on the order of $10^{-4}s^{-1}$. Another is an apparent wave motion direction error [Garcia et al., 2000], which states that while the averaged large-scale real electric field generates eastward movement during local nighttime hours, observations often display westward moving structures. Kelley and Makela, (2001) reconciled experimental and theory by invoking polarization of the Perkins structures in the direction parallel to their long axis.

Christos et al. (2003), propose that the enhanced polarization fields set up inside unstable sporadic-E patches can easily map up the magnetic field lines to the F region and thus contribute to the formation of midlatitude spread F. Yokoyama et al. (2009) performed a three-dimensional numerical model, which can simulate two instability mechanisms: Perkins instability in the F-region and sporadic-E (Es)-layer instability in the E region. They concluded that the Es-layer instability plays a major role in seeding NW-SE structure in the F region, and the Perkins instability is required to amplify its perturbation. In addition, on the night of 26-27 February 2006, a sporadic-E was observed near the tongue as showed by figures 4, 2 and 3, respectively. Around 02-03 UT there is an abrupt increase of the foF2 probably associated with the tongue of ionization.

Ionogram displaying traces characterizing the mid-latitude spread-F phenomenon (DBS/MSTID) signatures is presented in Figure 4. This results indicate that spread-Es is records for a short interval of time (approximately 1h) when tongues of ionization exist in the F region (highlight region in Figure 1 indicated by the black arrow). An enhancement at these times, of foEs is also indicated by the results in Figure 3 suggesting that the creating of the Es layer itself results from the generation of the "tongue" in the F layer. If tongues of ionization, whose influence sometimes extend down to the E-region, are intimately related to the occurrence of spread-F, as the results of this present paper would seem to suggest, this may be a starting experimental point in our quest for information on how or why spread-F irregularities are formed in the midlatitudes.

2.2. On the equatorial spread-F (Plasma Bubbles).

The equatorial spread-F (ESF) phenomenon, which show diffuse echoes on the ionograms during nighttime, have been the subject of intensive observational (ground-based optical, radio and radar techniques and in-situ satellite and rocket) and theoretical investigations for many years. The continuing interest in the studies related to the equatorial spread-F irregularities increased from its implications for trans-ionospheric communications and navigation systems. These irregularities are often characterized by transequatorial plasma-depleted magnetic flux tubes, referred to as plasma bubbles, and result from the Rayleigh-Taylor instability process. Using wide-angle imaging of the OI 630.0 nm nightglow, Weber et al. (1978) were the first to record quasi north-south (magnetically) aligned depleted intensity bands with coincident observations of the equatorial range-type spread-F.

Since the plasma bubbles drift at approximately the velocity of the background plasma, several investigations have been carried out to study the ionospheric plasma bubble zonal drift velocities utilizing radio waves [incoherent scatter radar (Woodman and Lahoz, 1976; Fejer et al., 1985)]. On the other hand, the ionospheric plasma bubble zonal drift velocities have been also studied using wide-angle airglow imaging techniques (Mendillo and Baumgardner, 1982; Fagundes et al., 1997; Pimenta et al., 2001a, Martinis et al., 2003, Abalde et al., 2004), as well as using scan OI 630 nm airglow photometers (e.g. Sobral et al., 1985, 1999). They have also been studied from vector electric field and ion drift measurements on board the Dynamics Explorer-2 satellite (e.g. Aggson et al., 1996; Anderson et al., 1987). In the present paper, a tropical plasma bubble appeared in the field of view around 02:36UT, propagating from west to east with average speed of about 50 m/s and around 03:47UT there is a coupling between the plasma bubble and DBS/MTID. Unfortunately after this time we do not OI630nm images because the sky became cloudy.

3. Summary

Simultaneous measurements of Dark Band Structures in the OI630.0 nm emission all-sky images associated with both Rayleigh-Taylor and Perkins instabilities are presented for the first time. The observed features can be summarized as follows:

1. Regarding to the DBS/MSTID, the most notable feature of the structure reported is their tendency to be aligned from northeast to southwest and to drift towards the northwest with average speed of 25 m/s. The dark structure produces spread-F in the F-region. We conjecture that the Perkins instability might be involved in the formation of DBS/MSTID.
2. The results presented indicate that spread-Es was recorded for a short interval (approximately 1h) of time when both spread-F and tongues of ionization were in the F-region.
3. Alternatively, one cannot exclude an explanation which proposes that the enhanced polarization fields set up inside unstable sporadic-E patches can easily map up the magnetic field lines to the F-region and thus contribute to the formation of midlatitude spread-F.
4. A tropical plasma bubble appeared in the field of view around 02:36UT, propagating from west to east with average speed of about 50 m/s and around 03:47UT there is a coupling between the plasma bubble and DBS/MTID. This is a special situation in which two different electrodynamical phenomena have been detected simultaneously, indicating the presence of a transition region.

Acknowledgement: We would like to thank the Ionosphere Group of INPE for kindly providing the ionospheric parameters obtained at Cachoeira Paulista. This work was partially supported by a grant number 2008/50553-8 from the financing agency FAPESP, Sao Paulo. Also, the authors acknowledge the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) through process 453062/2009-1.

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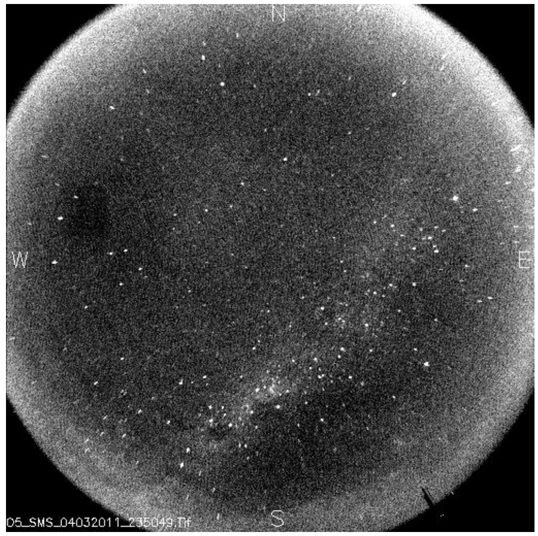

Figure 1 – All-sky image obtained in São Martinho da Serra-RS

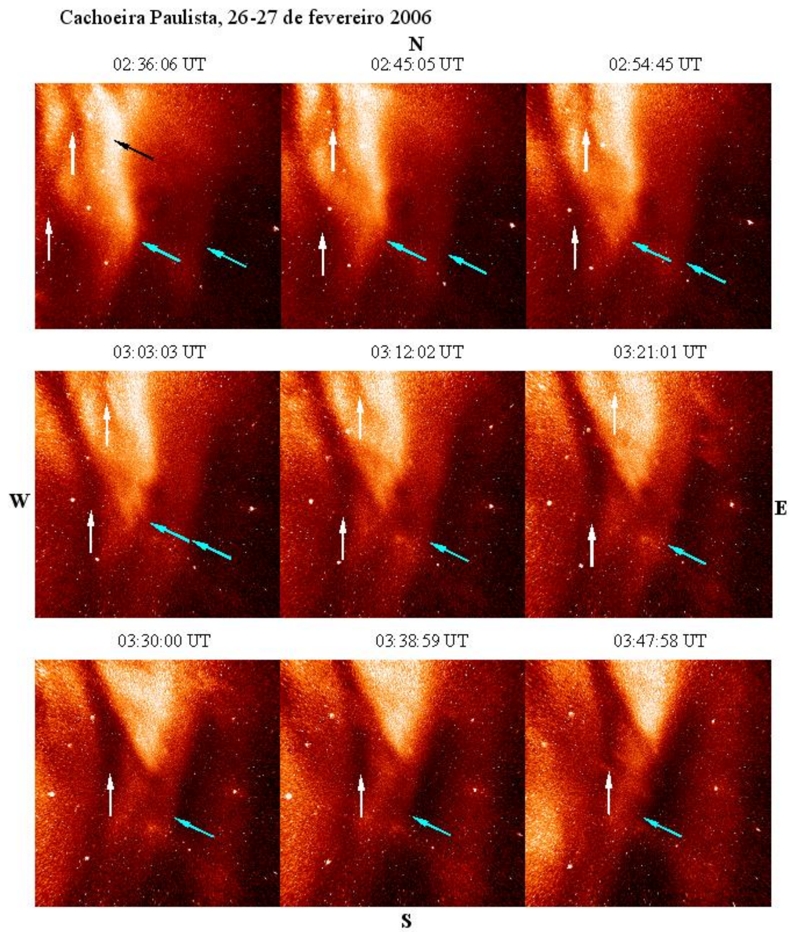

Figure 2 - All-sky images in the OI 630 nm emission obtained on February 26-27, 2006, from 02:36 UT to 03:47 UT. Unwarped image corresponding to a mapped area of the processed image of 1024km x 1024km at the OI 630 nm airglow layer, assuming an emission altitude of 275 km. Blue, white and black arrows, represent DBS/MSTID, plasma bubbles and tongue of ionization respectively.

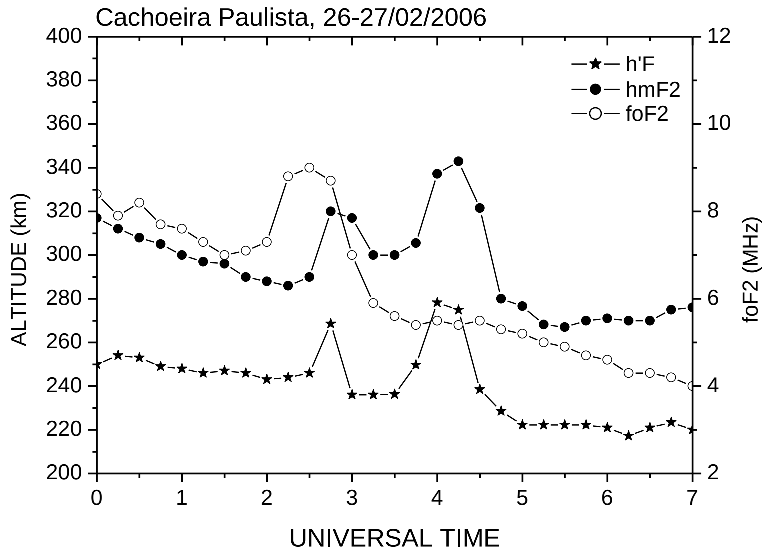

Figure 3 - Ionosonde observations registered abrupt increases in both the F-layer peak height (hpF2) and base height (h'F), when the DBS/MSTID passed over Cachoeira Paulista. Around 02-03 UT there is an abrupt increase of the foF2 probably associated with a tongue of ionization.

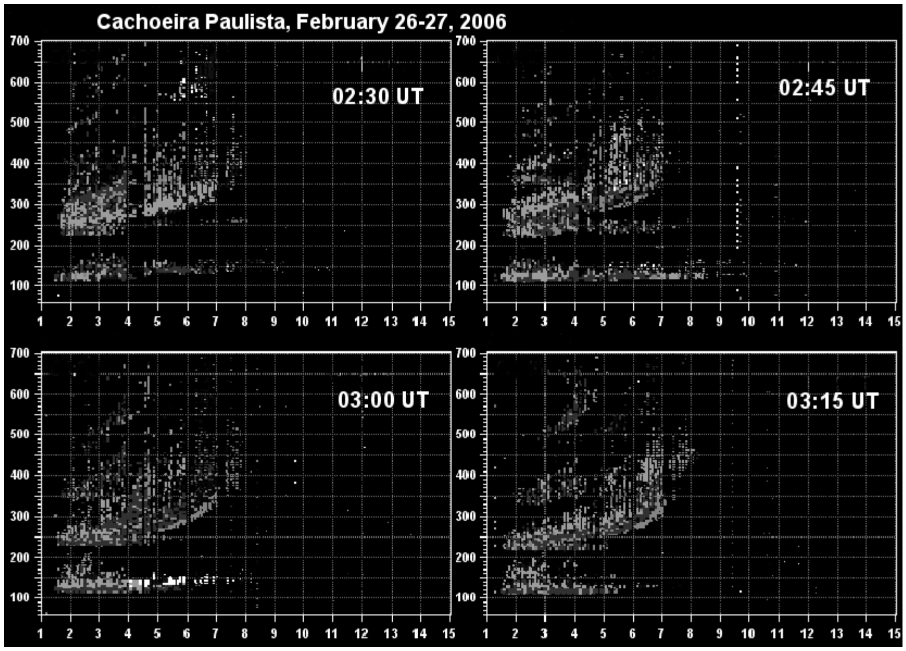

Figure 4 – Set of 4 standard ionograms showing spread-F and spread-Es occurrence on 26-27 February 2006.